The effect of slag basicity on spinal inclusion wettability

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Abstract
Steel cleanness is an important and growing research area driven by the demands to produce high quality steel. Inclusion content in steel is an important criterion to assess clean steel. MgO,Ah03 spinel inclusions cause problems in steel processing and are generally deleterious to steel products due to their high melting point and high hardness. Inclusions are generally removed by reacting with slag. This is primarily achieved by optimizing the process conditions to promote contact and reaction between the inclusion and slag. Efficient removal from the steel the inclusions must attach to and dissolve in the slag phase. If this attachment is weak, then local fluid conditions are likely to result in the shearing of this attachment and the inclusions re-entrainment in the steel. The strength of attachment (reactivity) between the inclusion and the slag phase can be characterized by the wettability of the slag on inclusions. Research on inclusion removal in steel refining is principally divided into categories of flotation of inclusion to the steel/slag interface and modification to improve reactivity/separation with the slag phase and dissolution in the slag phase.

Keywords
wettability, effect, inclusion, spinal, basicity, slag

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Steel cleanliness is an important and growing research area driven by the demands to produce high quality steel. Inclusion content in steel is an important criterion to assess clean steel. MgO-\(\text{Al}_2\text{O}_3\) spinel inclusions cause problems in steel processing and are generally deleterious to steel products due to their high melting point and high hardness.

Inclusions are generally removed by reacting with slag. This is primarily achieved by optimizing the process conditions to promote contact and reaction between the inclusion and slag. For efficient removal from the steel, the inclusions must attach to and dissolve in the slag phase. If this attachment is weak, then local fluid conditions are likely to result in the shearing of this attachment and the inclusions re-entrapped in the steel. The strength of attachment (reactivity) between the inclusion and the slag phase can be characterized by the wettability of the slag on inclusions. Research on inclusion removal in steel refining is principally divided into categories of flotation of inclusion to the steel/slag interface, modification to improve reactivity/separation with the slag phase, and dissolution in the slag phase.

Much research has been carried out on the dissolution of inclusions in slag. Monaghan and Chen and Valdez et al. used a laser scanning confocal microscope (LSCM) to investigate the effect of slag basicity on spinel dissolution they both found that the rate of dissolution of the spinel particles increases with increasing basicity of the slag. Wettability of slag on a substrate of an oxide representing the inclusion phase can be considered an indirect measurement of the inclusions reactivity with slag. However, there are only limited data on slag on typical inclusion phases. Recently Choi and Lee investigated the wettability of alumina on slag and concluded that for a slag with a given CaO/\(\text{SiO}_2\) ratio, an increase in \(\text{Al}_2\text{O}_3\) results in a decrease in wettability. This may in part be explained by the change in thermodynamic driving force of the reaction and/or a change in the physical characteristics of the slag with increasing alumina.

To fully understand the wetting behavior of the inclusion phase with liquid slag a similar technique as used by Choi and Lee has been developed to study alumina, spinel, calcium aluminates and iron sulfides in CaO-SiO\(_2\)-Al\(_2\)O\(_3\) slags. The dynamic contact angle for these systems will be measured using a modified sessile drop apparatus, though only measurements using on a spinel type inclusion are reported here.

The experiment involves allowing a liquid drop to spread over a substrate of solid material in an inert atmosphere and the measurement of the change in contact angle (\(\theta\)) with time. Key details of the experiment are given below.
- Slags used were based on ladle type slags. They have a CaO/Al₂O₃ ratio of 1.02, 1.24 and 1.52 and contain 9% SiO₂ and 6% MgO. The phase stability of the spinel-slag was calculated using MTDATA thermodynamic software and is given in Fig 1.
- Substrates were prepared using laboratory grade reagents. A high density substrate was achieved by using -38μm particle size of pre-fused spinel which was pressed and sintered at 1600 °C for 24 hours. Phases were confirmed by XRD analysis.
- In the sessile drop experiments the slag and substrate where not in contact when heated to 1500 °C the experimental temperature in an argon atmosphere. Once stabilized at temperature the slag was contacted to the substrate and its change in wetting on the substrate measured. A schematic of the experiment apparatus used is given in Fig 2. The experiment was carried out based on heating the slag and substrate to temperature but not in contact. The change in wetting was captured by high definition video and still frames were analysed using the ImageJ software package.

![Fig 1: phase stability diagram of spinel-slag](image1)

![Fig 2: A schematic of the sessile drop technique](image2)

- Calculation of the contact angle was based on the geometry of a spherical cap, given in Fig 3 (a) and calculated via equation (1) where R is the radius dissected by a base plane. Also shown in Fig 3 are wetting and non-wetting conditions that have θ<90° and θ>90° respectively.

\[
\frac{\theta}{2} = \tan^{-1} \frac{h}{a}
\]  

(1)

![Fig 3: (a) geometry of a sessile drop approximated by a spherical cap defined by radius of the base and height above basal plane (b) contact angle for wetting liquid, (c) contact angle for non-wetting liquid](image3)

- The liquid-solid interface was examined using SEM and EDS analysis.

Frames from a sessile drop experiment using spinel substrate reacting with a slag of C/A=1.24 is shown in Fig 4 from before time zero to 30 sec after time zero. The time that the slag left the Pt wire completely defined time zero. The preliminary results of contact angle measurements were compared with those by Choi and Lee, who looked at a similar type slag (C/A=1.26 containing 13% SiO₂) on alumina at 1600 °C. The results and comparison are
given in Figure 5. From this Figure it can be seen that the change in wetting in the two different studies have similar characteristic i.e. they start off high and decay quickly to something like a plateau value. Based on the current study it was found that the slag has lower $\theta$ with spinel than Choi and Lee $^3$ reported for alumina. It should be noted that the slag composition and temperature are not equivalent in these two studies. Further work will be undertaken to study wettability characteristics of slags on various (inclusion phase) substrates and to investigate the inclusion dissolution kinetics using laser scanning confocal microscopy.

Fig 4: frames of the sessile drop experiment

![Contact Angle Measurements](image)

**Fig 5:** contact angle measurements of current study compared with Choi and Lee's investigation

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